

ESA - IXO Optics Update

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High energy astrophysics post Newton and Chandra

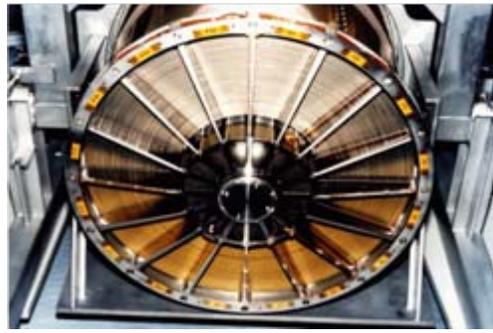
The combination of the following requirements appears not to be achievable with the currently established optics technologies:

- Large effective area over a large energy bandwidth
- Good angular resolution
- Mass budget constraint
- Temperature control limitations

Mounted X-ray Optics Technologies: Resolution and Mass



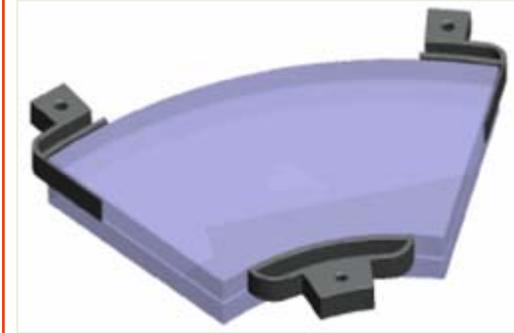
CHANDRA
0.5"
18500 kg/m²
A_{eff} @ 1 keV



XMM-NEWTON
14"
2300 kg/m²
A_{eff} @ 1 keV



Si-HPO
5"
200 kg/m²
A_{eff} @ 1 keV

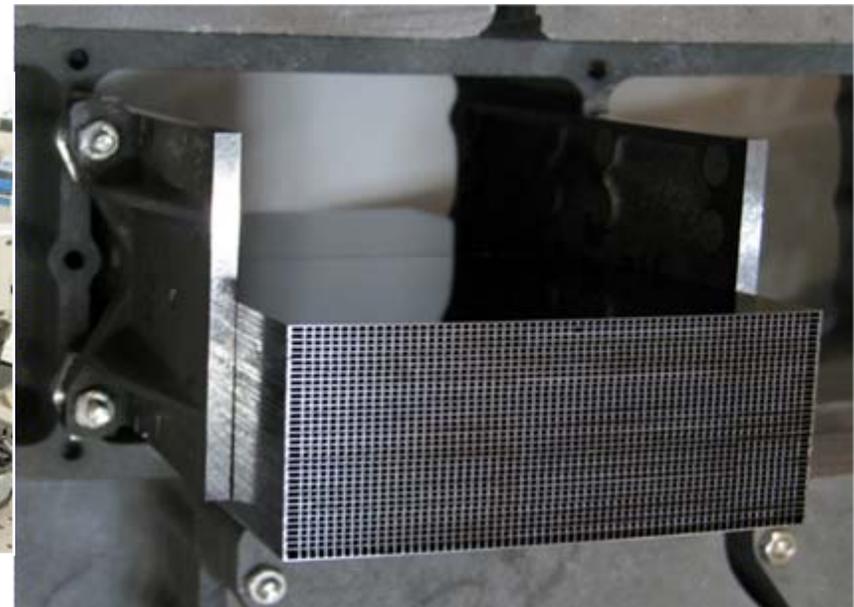
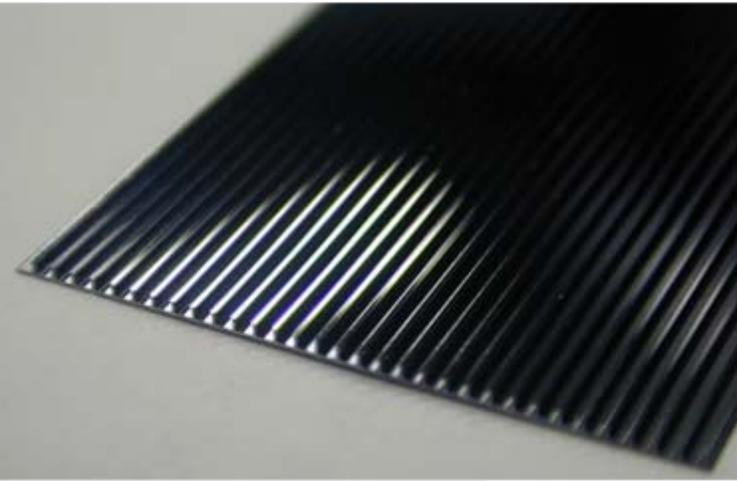


Glass-MPO
30"
25 kg/m²
A_{eff} @ 1 keV

One IXO Baseline

Other IXO baseline: glass plate optics

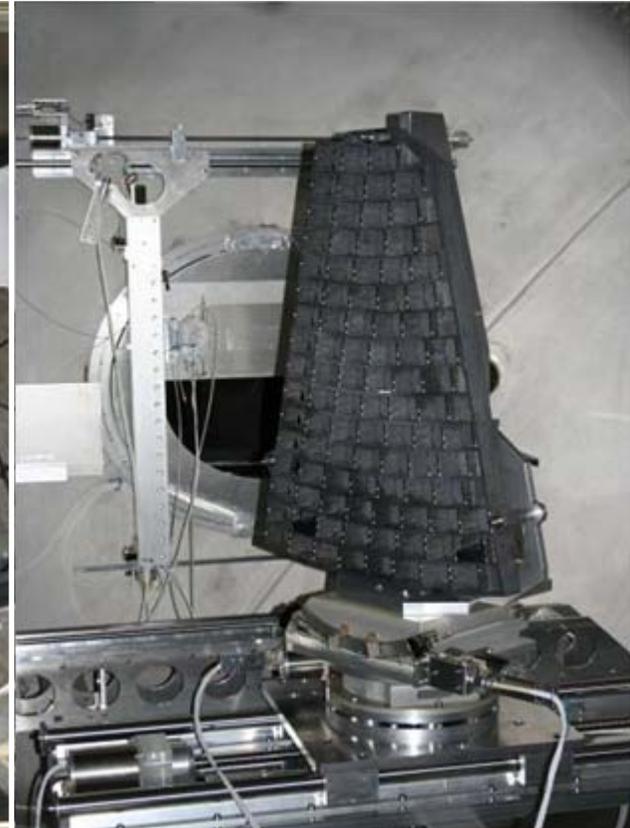
SPO: from mirror plates to Mirror Module and Petal: A multi-industrial/institutional undertaking



Status

- Last ESA TDA ended Oct 07 with demonstration of focusing optic made of wedged plates at PANTER
 - Entire production chain, from wafer up to petal, was addressed and demonstrated on prototype level.
- New ESA TDA Nov 07 – May 09 with the following goals:
 - Concentrate on stack, improve figure, demonstrate 5”
 - Develop coating methods
 - Explore manufacture of inner radii
- Additional activities
 - Had to change plate supplier, successful
 - Demonstrates that technology can be transferred
 - Re-analyse XOU stiffness, due to system level activities

Technology Development Activity: Prototype Petal (industrial activity)



ESA TDP overview: IXO Optics

**MM Performance
Demo**

**MM Ruggedizing
& Testing**

Petal Breadboard

**Industrialised
Mass Production**

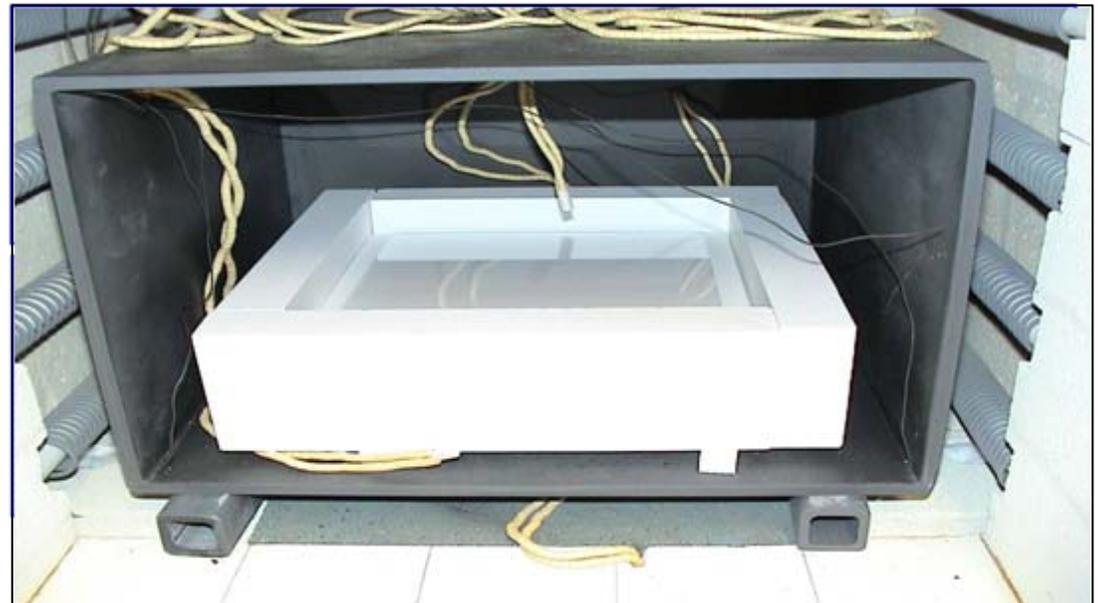
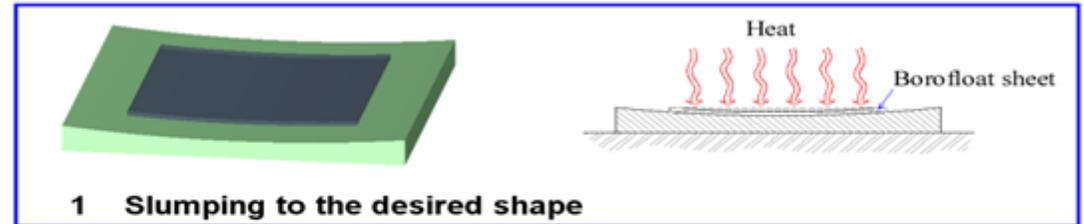
**Back-up Optics
Technology, part 1**

**Back-up Optics
Technology, part 2**

MPE: Indirect Slumping glass approach

Pros: The reflecting surface of the glass is not in contact with the mould, in order to preserve the initial microroughness level.

Cons: it needs a high thickness uniformity.



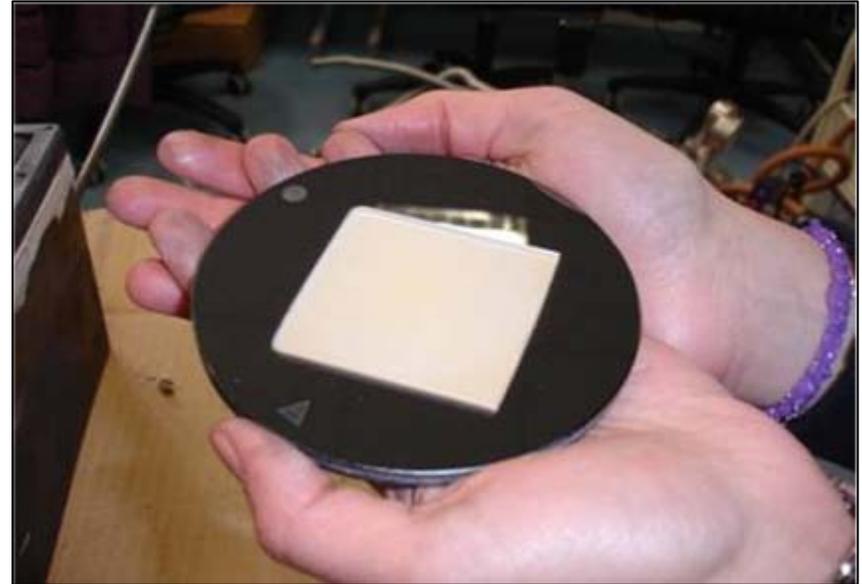
MPE: Max Planck Institut für Extraterrestrische Physik

Avoiding the adhesion of the SiC mould to the Glass. Test with a layer (40nm) of Pt on glass (OAB)

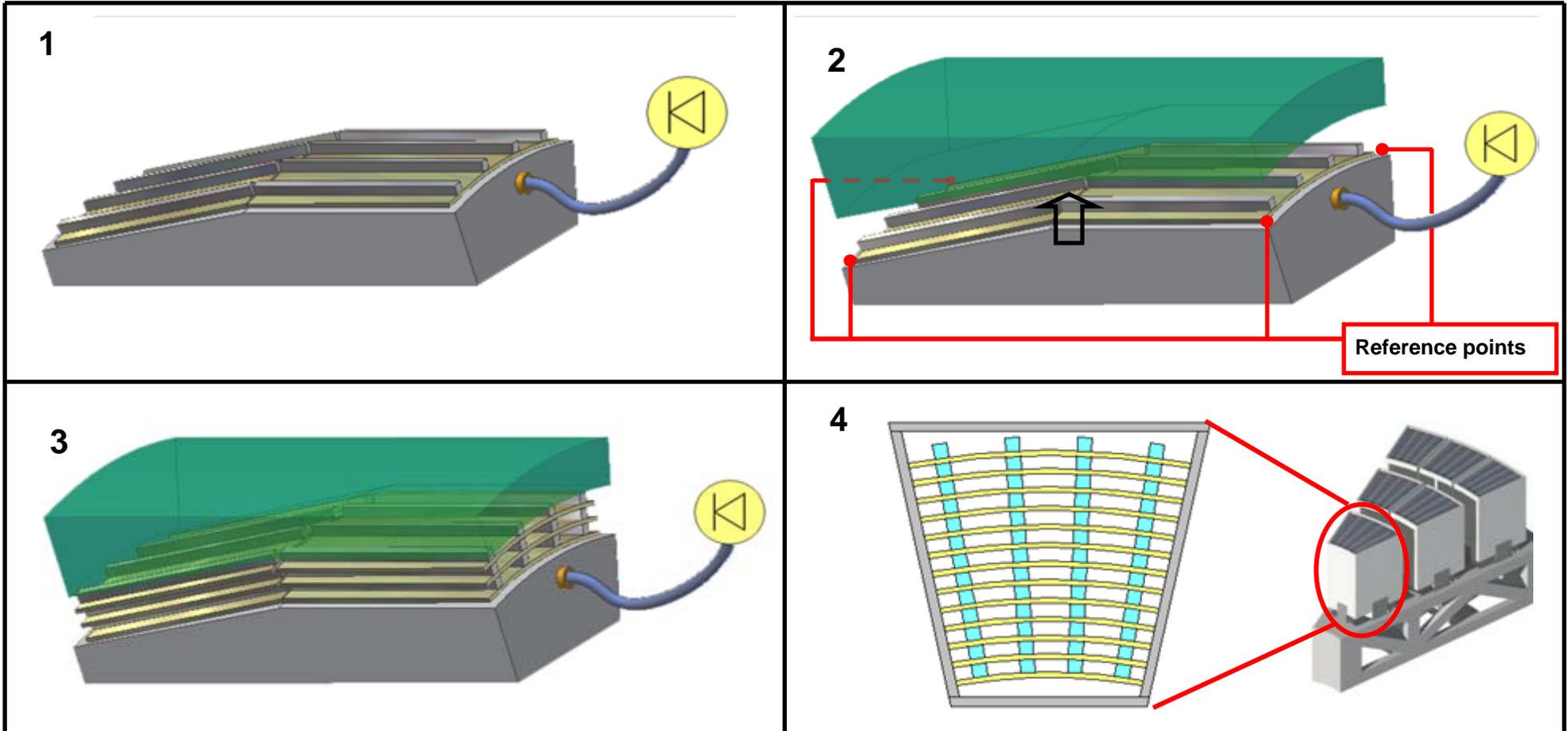
The advantages are:

- The Pt act as a release agent for mould separation
- The Pt act as X-ray reflecting coating
- The thermal cycle enhance the Pt adhesion on the glass
- The stresses of the Pt on the glass are relaxed

OAB: Brera Astronomical Observatory



Integration of the slumped segments into the module (OAB)



Proposed Tool for the glass segment integration process (porous graphite) (OAB)



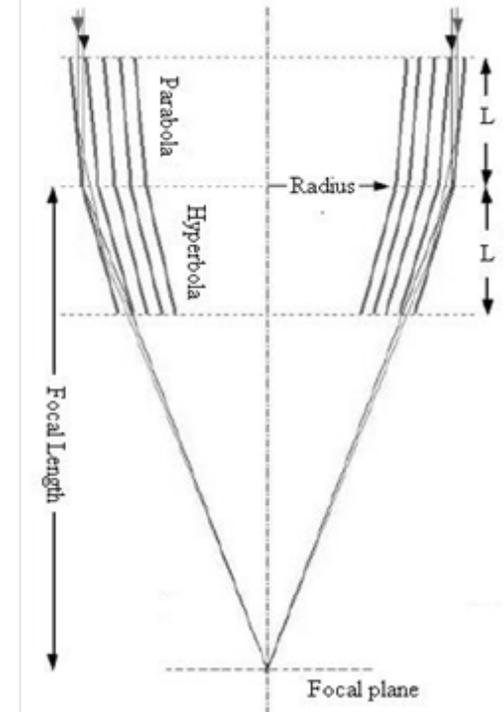
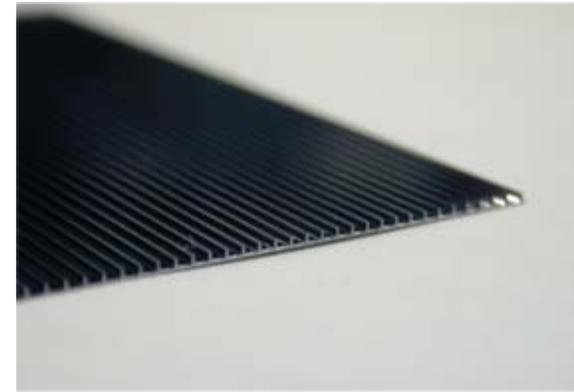
Concave and convex air bearings



These tools (in the flat configuration) are already used in the Flat Panel LCD industry for the handling of the thin glass sheets composing the LCD screens

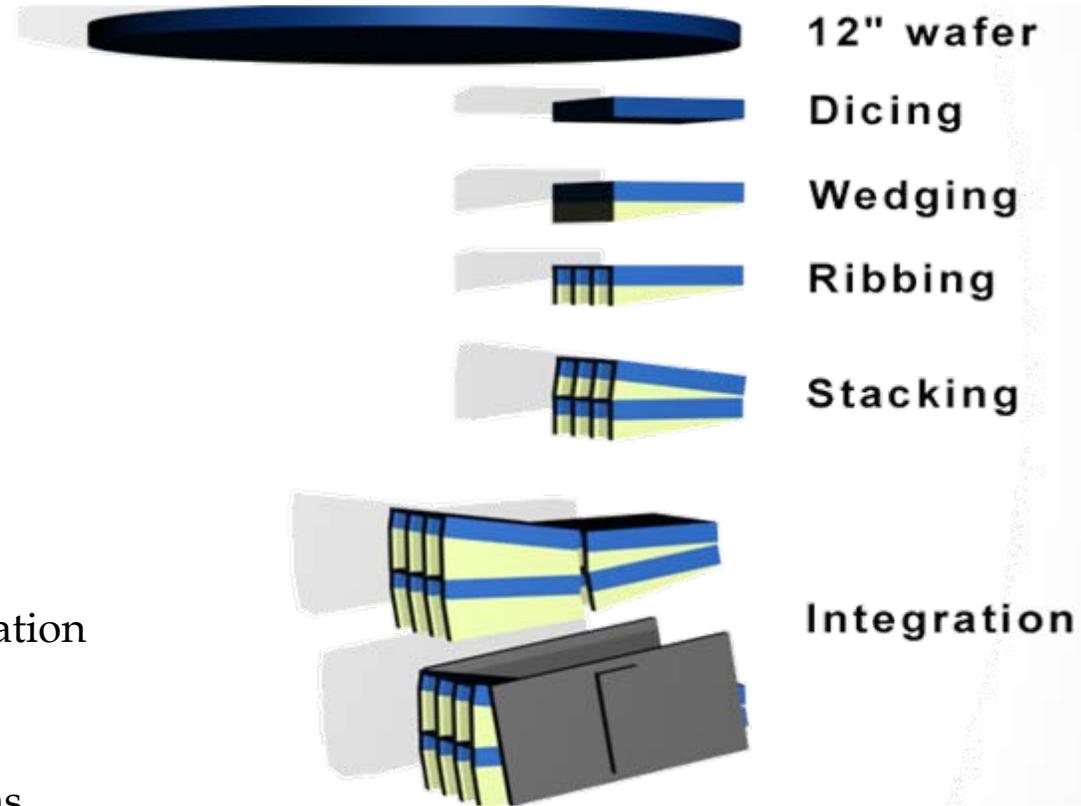
Silicon Pore Optics (1/2)

- Future X-ray telescope optics
 - Low mass $< 200 \text{ kg/m}^2$
 - High resolution 5 arcsec
 - Large effective area 3 m^2
- Novel technology: **silicon millipore optics**
 - Beijersbergen et al., SPIE 5488, p. 868 (2004)
- Uses commercial high-quality 12" silicon wafers
 - plan-parallel $< 0.6 \mu\text{m}$ over 300 mm
 - TTV 0.2 - 0.6 μm over 300 mm
 - large-scale production, cheap
- Surface finish
 - determined during wafer production
 - $50 \times 50 \mu\text{m}^2 \sigma_{\text{rms}} < 0.1 \text{ nm}$ (AFM)
 - $1 \times 1 \text{ mm}^2 \sigma_{\text{rms}} < 0.4 \text{ nm}$ (Chapman, cut-off 250 μm)
 - not significantly influenced by dicing, ribbing and assembly process
- Optics performance (angular resolution, PSF):



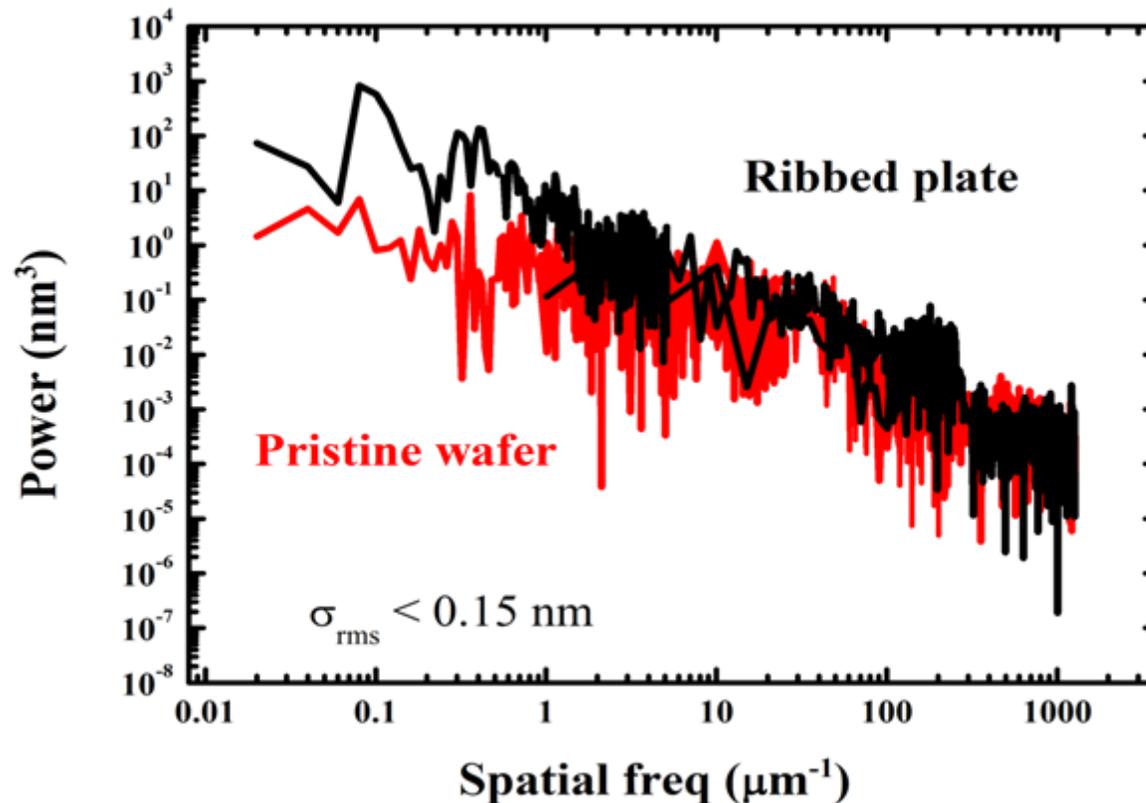
Silicon Pore Optics (2/2)

- Ribbed Si plate stacking
 - diced and ribbed (66 x 66 mm², 64 ribs)
 - elastically bent into a cylindrical shape
 - directly bonded on top of each other
- Stacking process established
 - Automated
 - Routine production
 - Currently up to 35 plates
- Tandem integration
 - Developed AIT procedures
 - Installed dedicated metrology
 - Assembly directly under X-ray illumination
 - Can set and fix kink-angle between two mirrors to 1" accuracy
 - Verified by assembly of several tandems
- X-ray performance testing
 - Testing mounted optics in double reflection

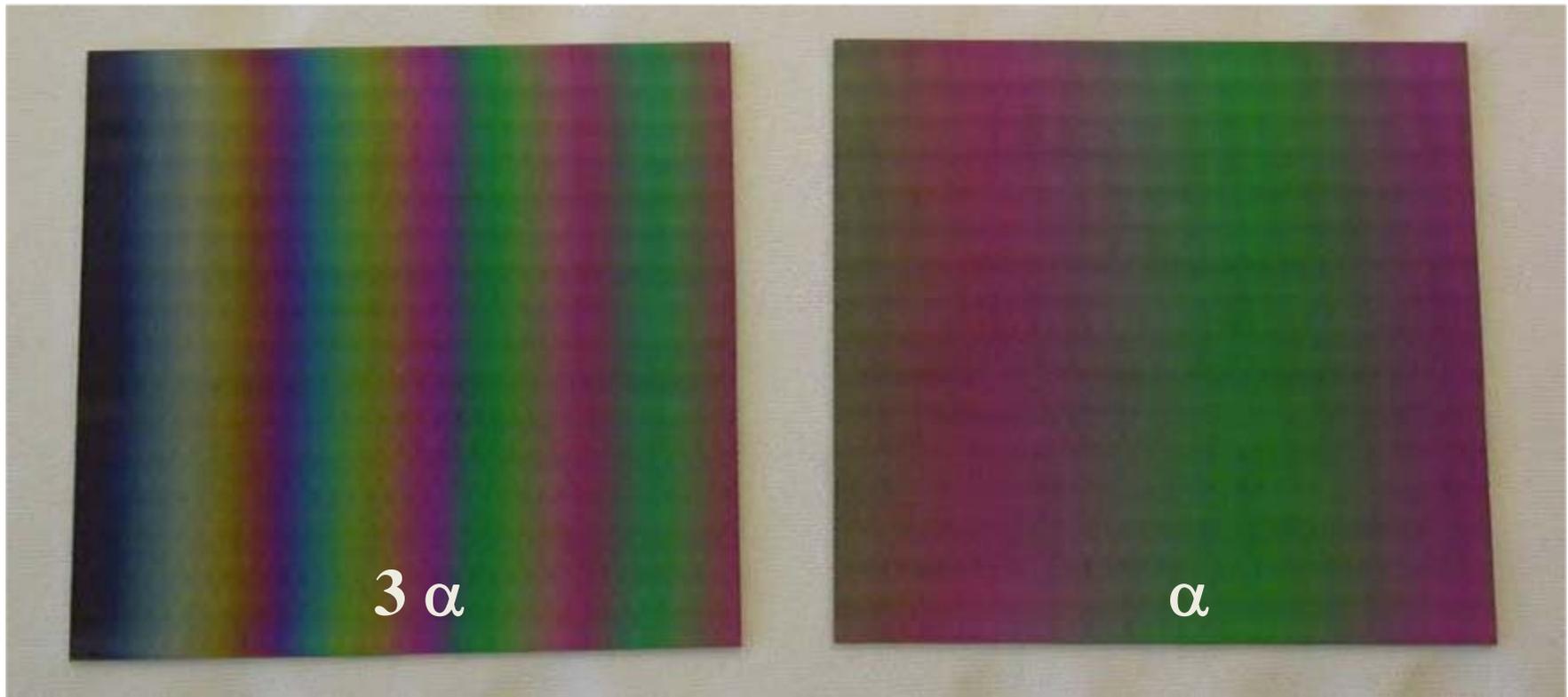


Reflective surface characterization

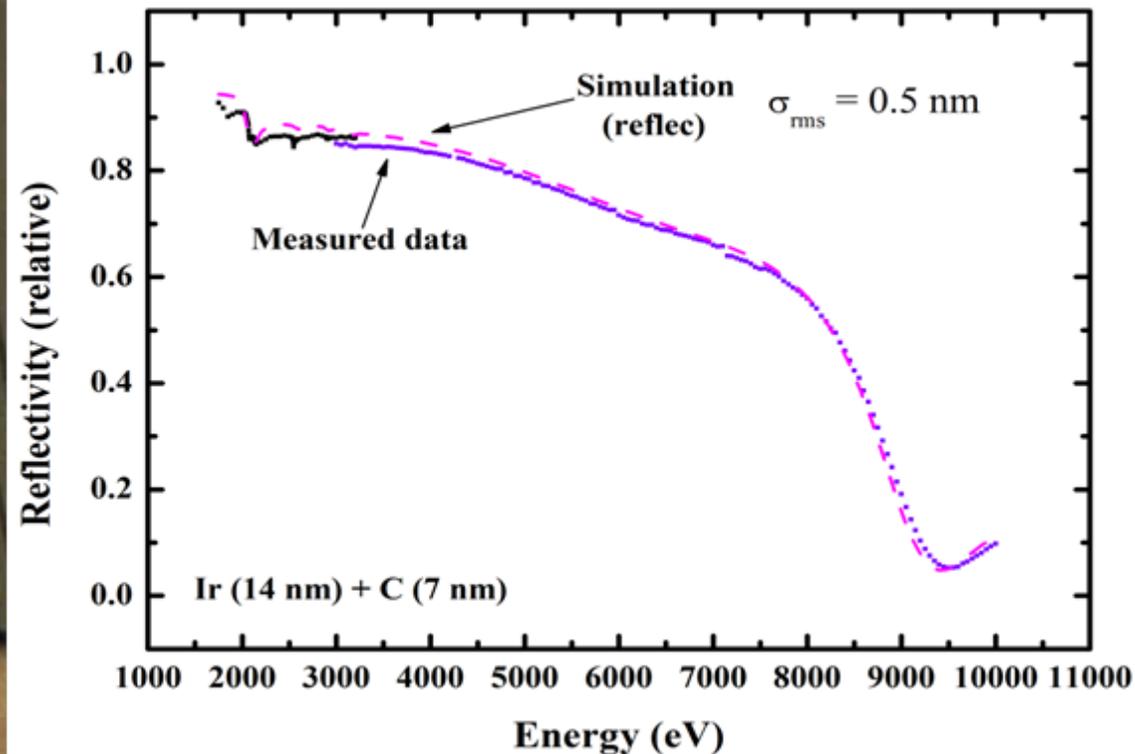
- Systematic characterization of surfaces as function of different process steps
- Combining different techniques (AFM, XRD, Chapman, Interferometry) to access full spatial frequency range from nm^{-1} up to cm^{-1}



Wedged Mirror Plates manufactured and stacked



Masked coating trials by DNSC (W, Pt), Ongoing: patterned C-Ir mirror plates

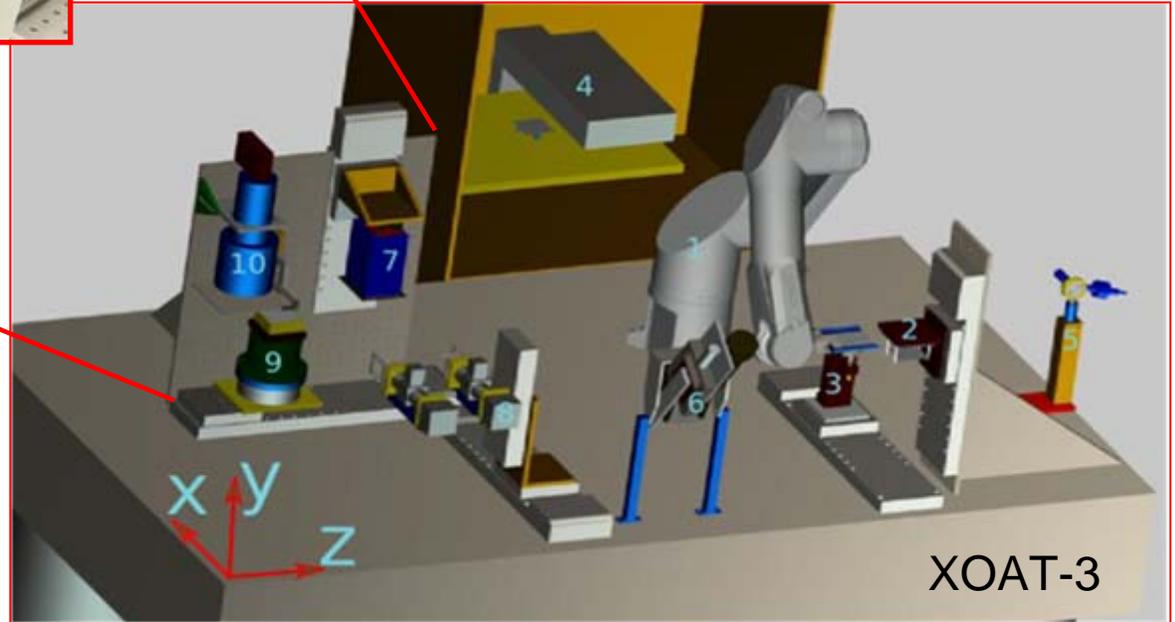


Stacking robot development



Working on three areas:

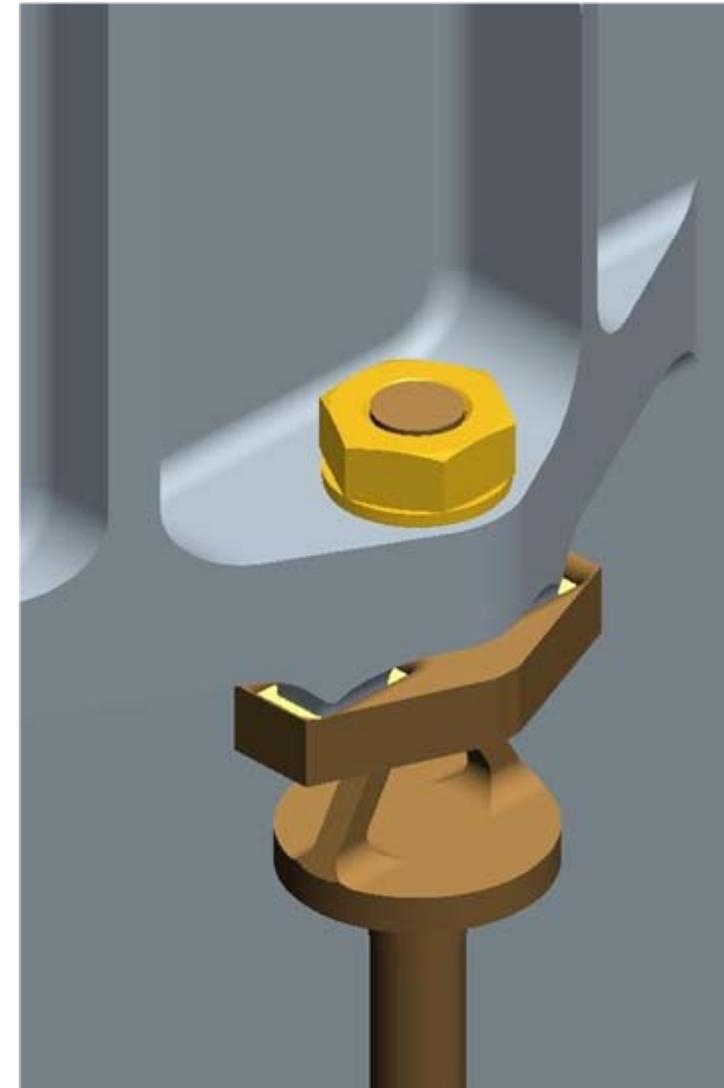
- Automated particle detection and removal
- Improved stacking figure
- Modularity



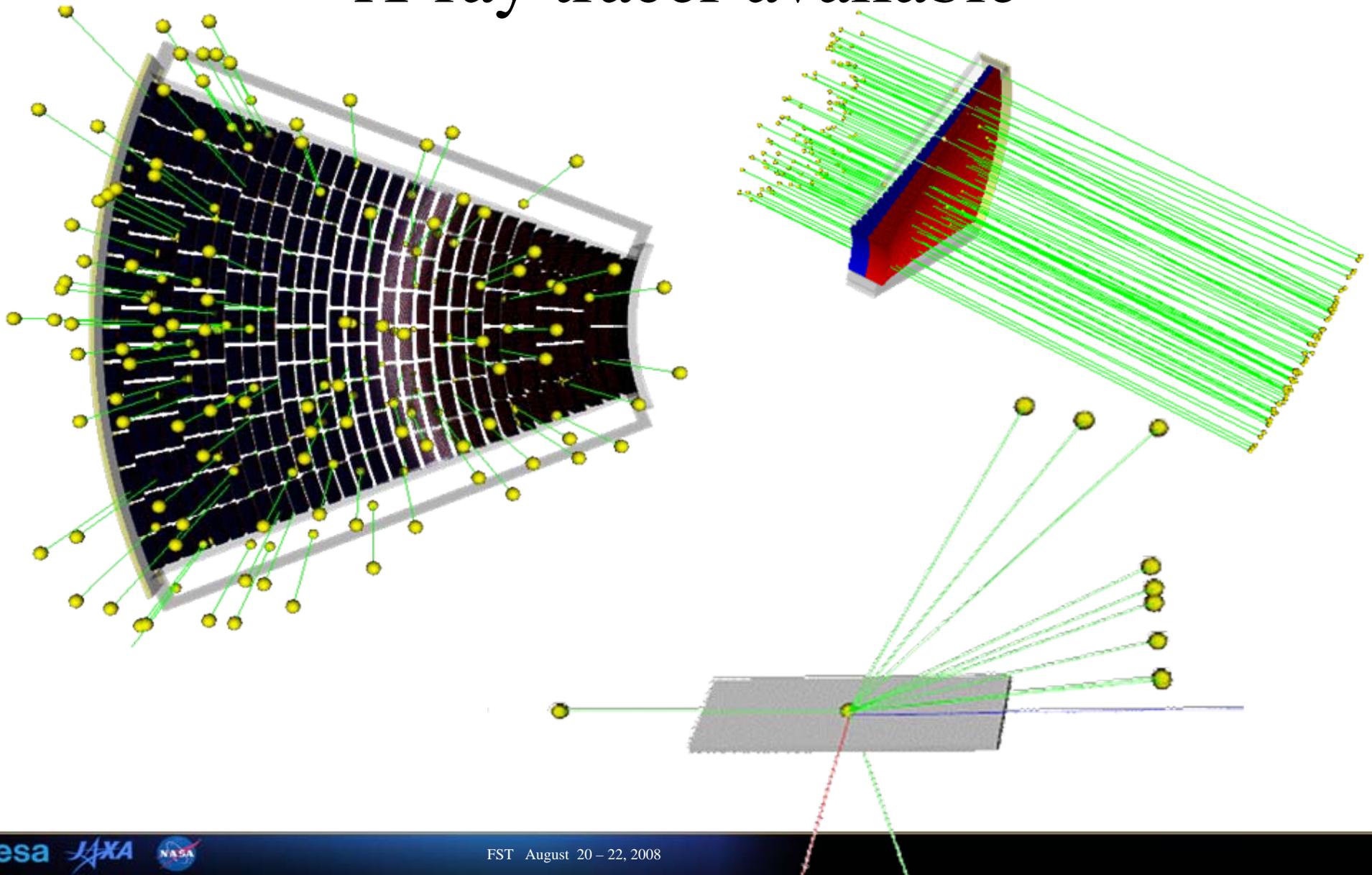
XOAT: X-ray Optics Assembly Tool

FEM analysis

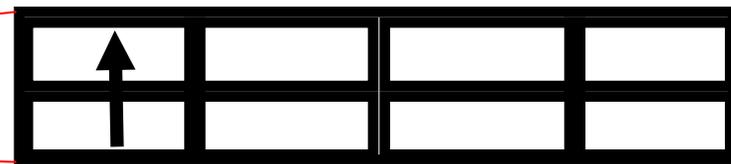
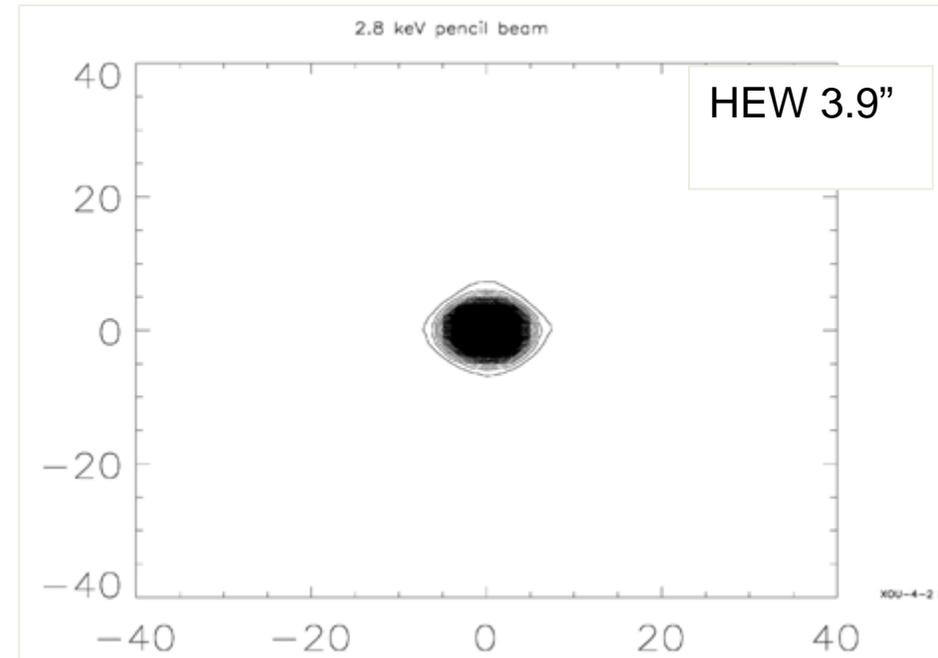
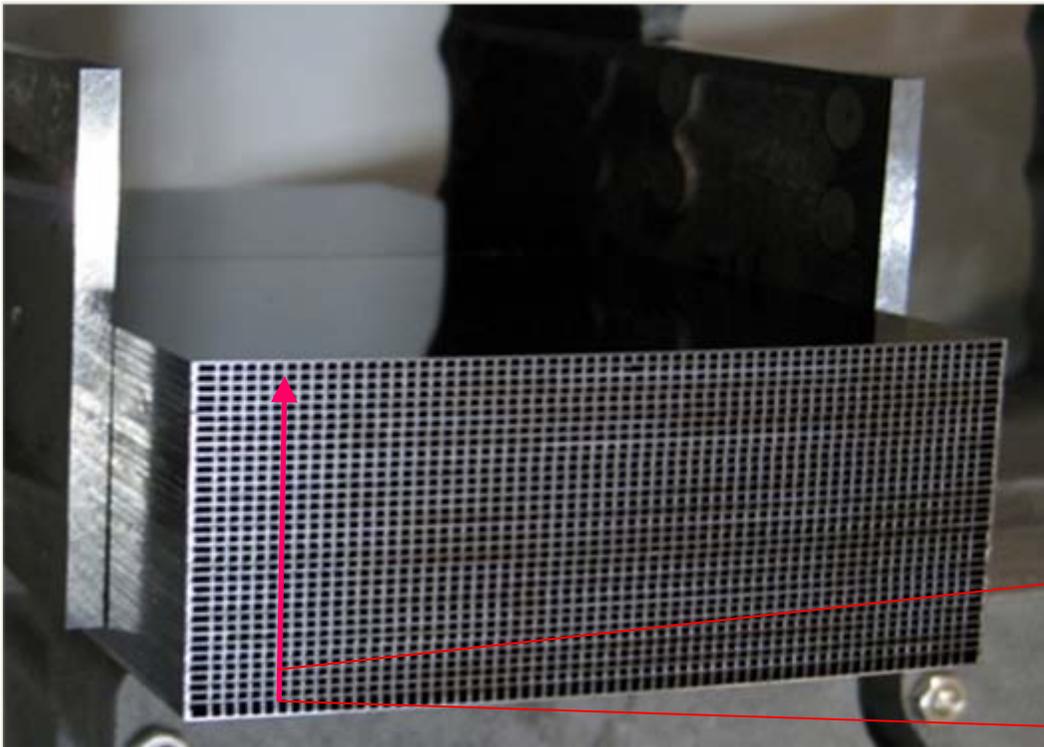
- Current Cesic bracket design OK after re-analysis
 - Resonance frequencies for inner and outer radii above 490 Hz
 - Safety factor of 3 considered
- Interface bracket/petal (“dowel pin”) has been improved
 - Have found simple solution that is fully iso-static
 - Improved dowel pins to further increase safety margins
 - for higher quasi-static launch loads (100 → 130 g)
 - different AIV procedure (interface unflatness)
- Will be tested in in 2008



X-ray tracer available



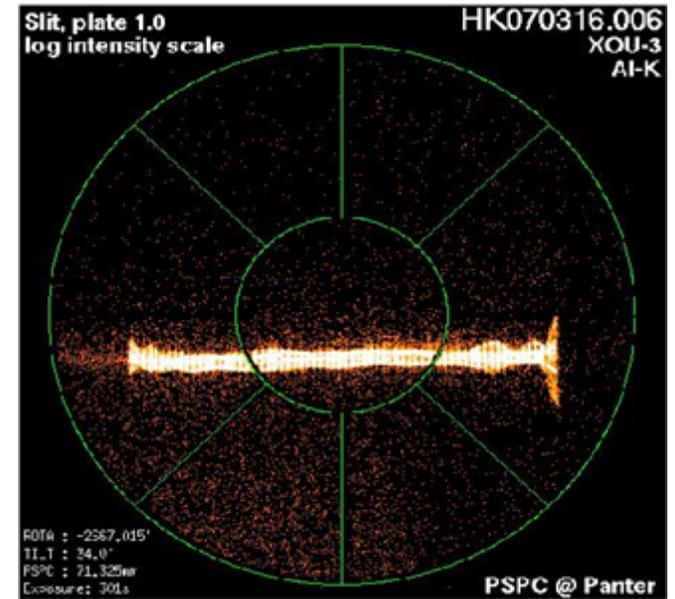
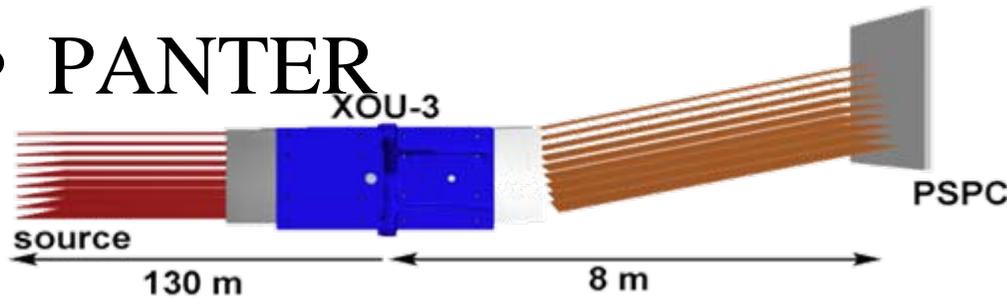
Pencil beam metrology at BESSY:



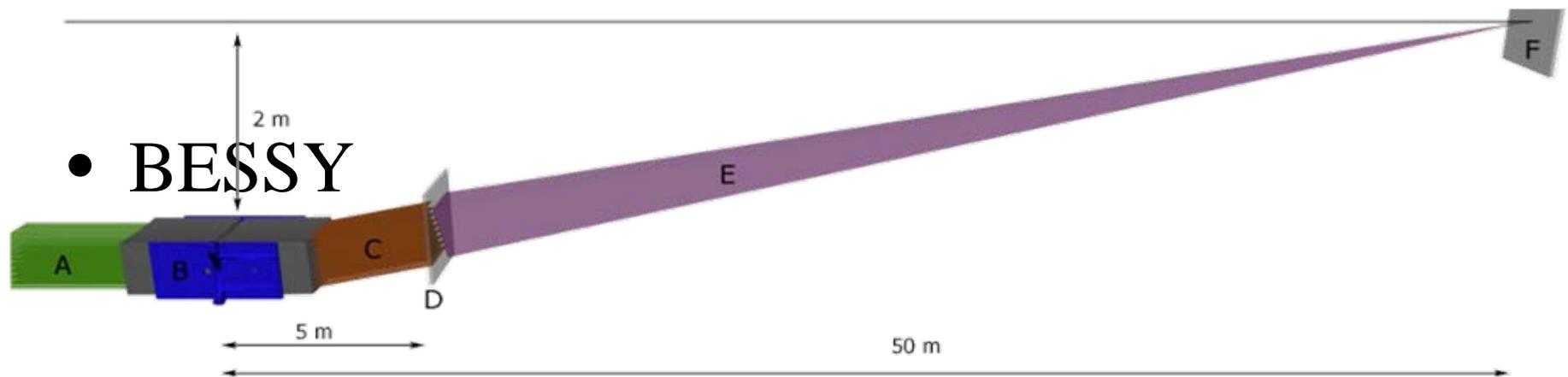
**50 μ m X-ray beam,
scans over full length of mirror**

Complementary full-beam metrology at Panter

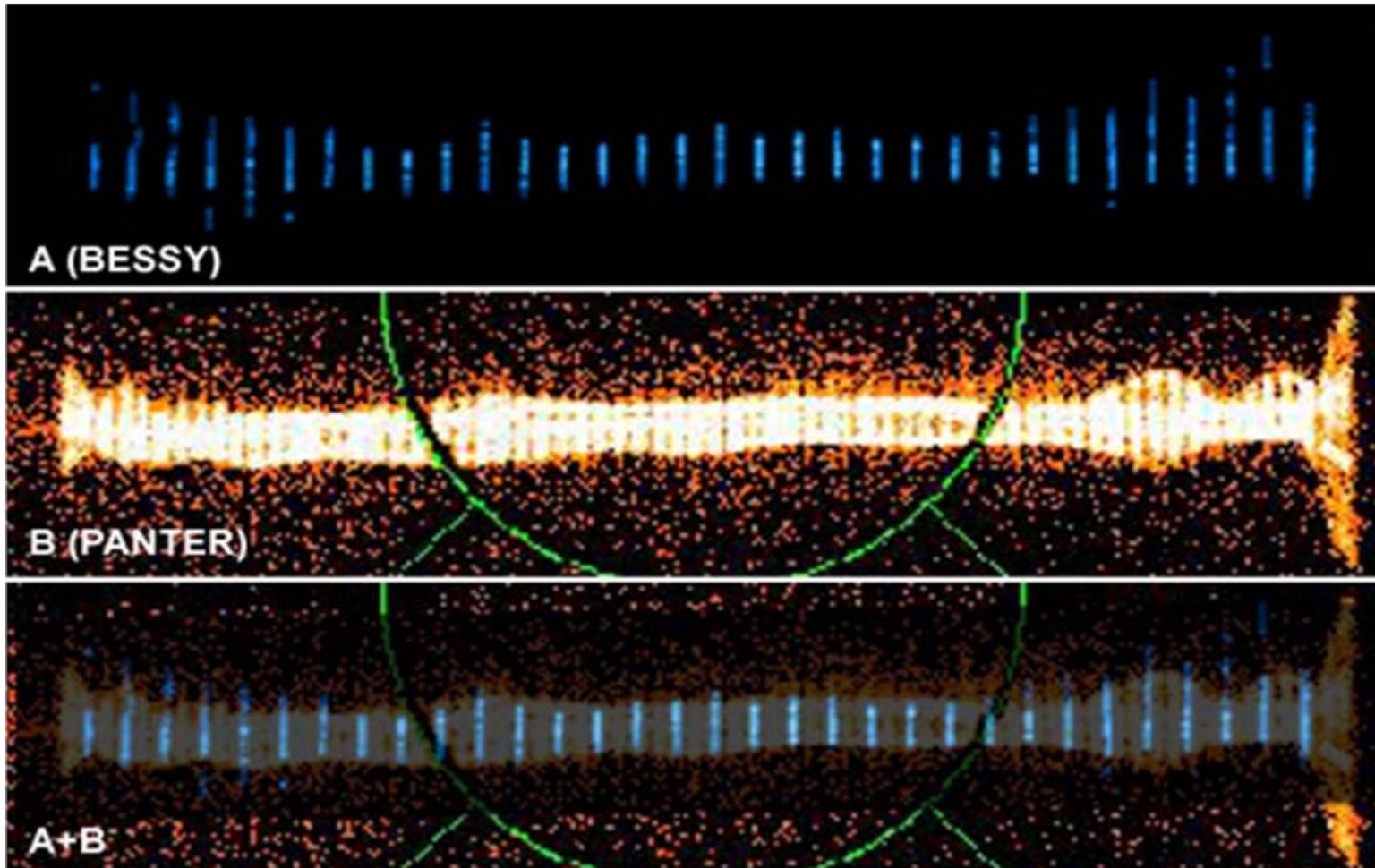
- PANTER



- BESSY

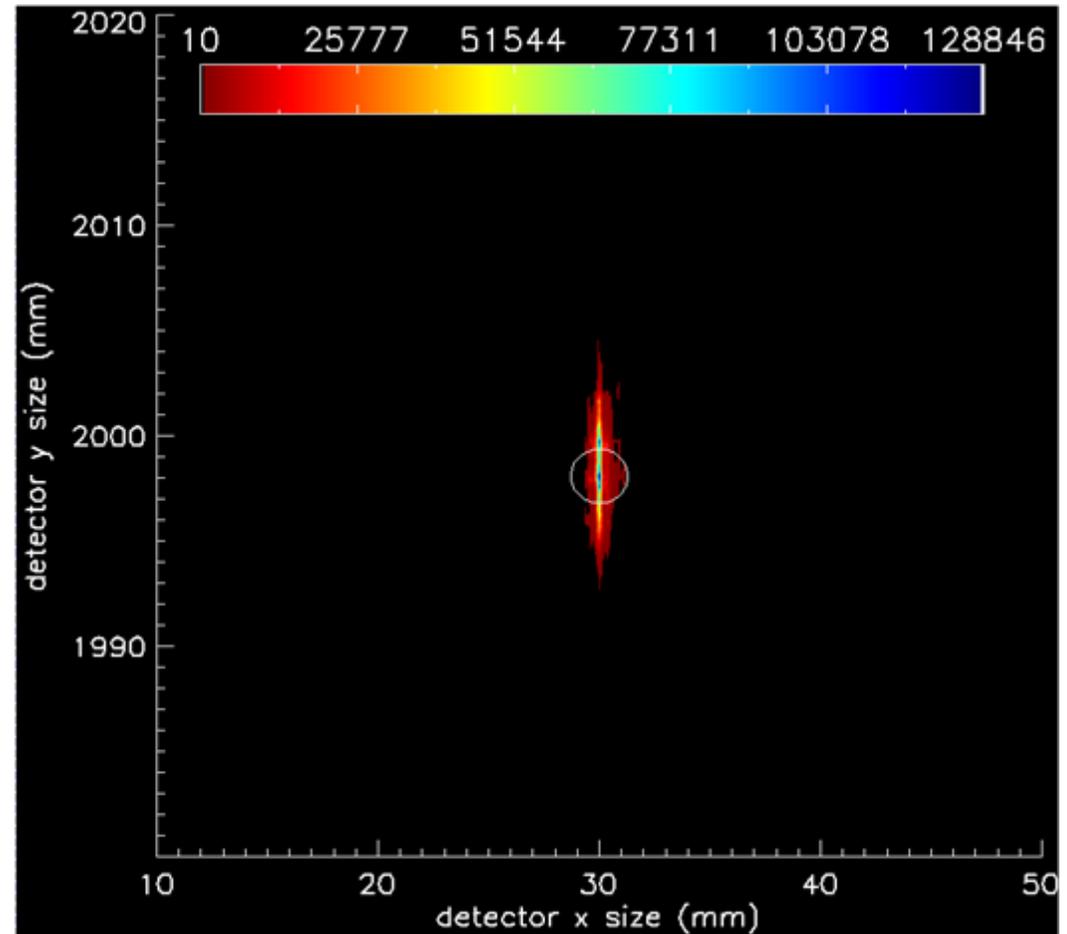


Full area (PANTER) versus pencil beam (BESSY2)



Current performance

- HEW 17" @ 50 m
 - double reflection
 - mounted optics
 - absolute
 - no subtraction
- Plates 1-4
 - full width



$A_{col} = 1.25 \text{ cm}^2$ (= 13% of innermost XMM mirror shell)

Summary X-ray test results

- Alignment and integration concept verified
 - Stack → tandem integration successful
 - Tandem → petal integration successful
- Measured 4 tandems and several stacks at PANTER
 - Facility set up to test from mandrel up to petal level
- No measurable influence of gravity on figure
 - Measure figure of a tandems at 0° and 90° rotation around the optical axis
- No measurable distortion of the tandems once integrated into the petal
 - Performance *before* and *after* integration the same
- Sub-aperture illumination
 - Particle errors can be tracked from plate to plate
 - Exposures at larger grazing angles can be used to analyse smaller parts of the mirror surface
- Wedged XOUs perform as expected
- Correlated BESSY and PANTER.

- **Demonstrated 17" HEW on mounted optics, no subtraction, full width, first 4 plates, double reflection**

Conclusions

- Challenging requirements on optics technology for post XMM/Newton & Chandra high energy astrophysics observatories
- Encouraging results from industrial developments of Silicon Pore X-ray Optics Technology
- Technology Development Programme in place and being implemented by ESA, addressing performance/coatings, environmental qualification and mass production issues
- ESA has Silicon Pore Optics as baseline and Glass Optics as backup in Technology Development Plan for 2008-2011